CLAIMS

1. A computer system configured by machine instructions to operate as a virtual machine that responds to virtual-machine code, which virtual-machine code defines a mutator that dynamically allocates memory in a heap to data objects and writes in reference fields references to such objects, by:

    A) executing a garbage collector that:

        i) treats the heap as divided into regions;

        ii) determines whether objects to which memory in the heap has been dynamically allocated satisfy a popular-object criterion;

        iii) places into certain, popular-object regions the objects that it thereby determines satisfy such a criterion and excludes from such regions objects that it thereby determines do not satisfy such a criterion;

        iv) maintains for each of a plurality of the regions other than the popular-object regions a respective remembered set that lists where references in other regions to that region have been written; and

        v) updates the remembered sets in response to reference-written notifications from the mutator; and

    B) so executing the mutator that, in at least some situations in which the mutator writes a reference into a reference field in the heap, the mutator:

        i) makes a normal-region determination of whether the reference refers to an object that is not located in a popular-object region;

        ii) makes a reference-written notification to the garbage collector if the normal-region determination's result is that the reference refers to an object that is not located in a popular-object region; and

        iii) otherwise refrains from making such a notification.

2   A computer system as defined in claim 1 wherein:

    A)   the garbage collector treats the heap as additionally divided into cards;

    B)   the mutator maintains at least one remembered-set log; and

    C)   the reference-written notification includes placing into one such remembered-set log an identifier of the card in which the reference's containing object starts.

3   A computer system as defined in claim 1 wherein the garbage collector makes a popular-region determination of whether regions that are not popular-object regions satisfy a popular-region criterion and, when such a region is thereby determined to satisfy the popular-region criterion:

    A)   counts references to objects in the region with which that remembered set is associated; and

    B)   places into popular-object regions objects to which the numbers of references are thereby found to exceed a popular-object threshold.

4.   A computer system as defined in claim 3 wherein the garbage collector makes the popular-region determination as part of maintaining the remembered sets.

5.   A computer system as defined in claim 1 wherein the normal-region determination's result is negative if the reference satisfies a popular-object-region criterion.

6.   A computer system as defined in claim 5 wherein the popular-object-region determination's result is negative if the reference is a distinguished, NULL value that indicates that the reference refers to no object.

7.   A computer system as defined in claim 6 wherein the popular-object-region criterion is that the reference's value be less than a popular-object-region threshold.

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1   8.   A computer system as defined in claim 7 wherein the NULL value is less than the

2   popular-object-region threshold.

1   9.   A storage medium containing instructions readable by a computer system to con-

2   figure the computer system to operate as a virtual machine that responds to virtual-

3   machine code, which virtual-machine code defines a mutator that dynamically allocates

4   memory in a heap to data objects and writes in reference fields references to such objects,

5   by:

6   A)   executing a garbage collector that:

7   i)   treats the heap as divided into regions;

8   ii)   determines whether objects to which memory in the heap has been

9   dynamically allocated satisfy a popular-object criterion;

10   iii)   places into certain, popular-object regions the objects that it

11   thereby determines satisfy such a criterion and excludes from such

12   regions objects that it thereby determines do not satisfy such a cri-

13   terion;

14   iv)   maintains for each of a plurality of the regions other than the popu-

15   lar-object regions a respective remembered set that lists where ref-

16   erences in other regions to that region have been written; and

17   v)   updates the remembered sets in response to reference-written noti-

18   fications from the mutator; and

19   B)   so executing the mutator that, in at least some situations in which the mu-

20   tator writes a reference into a reference field in the heap, the mutator:

21   i)   makes a normal-region determination of whether the reference re-

22   fers to an object that is not located in a popular-object region;

23   ii)   makes a reference-written notification to the garbage collector if

24   the normal-region determination's result is that the reference refers

25   to an object that is not located in a popular-object region; and

26   iii)   otherwise refrains from making such a notification.

10   A storage medium as defined in claim 9 wherein:

A)   the garbage collector treats the heap as additionally divided into cards;

B)   the mutator maintains at least one remembered-set log; and

C)   the reference-written notification includes placing into one such remembered-set log an identifier of the card in which the reference's containing object starts.

11   A storage medium as defined in claim 9 wherein the garbage collector makes a popular-region determination of whether regions that are not popular-object regions satisfy a popular-region criterion and, when such a region is thereby determined to satisfy the popular-region criterion:

A)   counts references to objects in the region with which that remembered set is associated; and

B)   places into popular-object regions objects to which the numbers of references are thereby found to exceed a popular-object threshold.

12.   A storage medium as defined in claim 11 wherein the garbage collector makes the popular-region determination as part of maintaining the remembered sets.

13.   A storage medium as defined in claim 9 wherein the normal-region determination's result is negative if the reference satisfies a popular-object-region criterion.

14.   A storage medium as defined in claim 13 wherein the popular-object-region determination's result is negative if the reference is a distinguished, NULL value that indicates that the reference refers to no object.

15.   A storage medium as defined in claim 14 wherein the popular-object-region criterion is that the reference's value be less than a popular-object-region threshold.

1   16.   A storage medium as defined in claim 15 wherein the NULL value is less than the

2   popular-object-region threshold.

1   17.   An electromagnetic signal representing instructions readable by a computer sys-

2   tem to configure the computer system to operate as a virtual machine that responds to vir-

3   tual-machine code, which virtual-machine code defines a mutator that dynamically allo-

4   cates memory in a heap to data objects and writes in reference fields references to such

5   objects, by:

6   A)   executing a garbage collector that:

7   i)   treats the heap as divided into regions;

8   ii)   determines whether objects to which memory in the heap has been

9   dynamically allocated satisfy a popular-object criterion;

10   iii)   places into certain, popular-object regions the objects that it

11   thereby determines satisfy such a criterion and excludes from such

12   regions objects that it thereby determines do not satisfy such a cri-

13   terion;

14   iv)   maintains for each of a plurality of the regions other than the popu-

15   lar-object regions a respective remembered set that lists where ref-

16   erences in other regions to that region have been written; and

17   v)   updates the remembered sets in response to reference-written noti-

18   fications from the mutator; and

19   B)   so executing the mutator that, in at least some situations in which the mu-

20   tator writes a reference into a reference field in the heap, the mutator:

21   i)   makes a normal-region determination of whether the reference re-

22   fers to an object that is not located in a popular-object region;

23   ii)   makes a reference-written notification to the garbage collector if

24   the normal-region determination's result is that the reference refers

25   to an object that is not located in a popular-object region; and

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26   iii)   otherwise refrains from making such a notification.

1   18   An electromagnetic signal as defined in claim 17 wherein:

2   A)   the garbage collector treats the heap as additionally divided into cards;

3   B)   the mutator maintains at least one remembered-set log; and

4   C)   the reference-written notification includes placing into one such remem-

5   bered-set log an identifier of the card in which the reference's containing

6   object starts.

1   19   An electromagnetic signal as defined in claim 17 wherein the garbage collector

2 makes a popular-region determination of whether regions that are not popular-object re-

3 gions satisfy a popular-region criterion and, when such a region is thereby determined to

4 satisfy the popular-region criterion:

5   A)   counts references to objects in the region with which that remembered set

6   is associated; and

7   B)   places into popular-object regions objects to which the numbers of refer-

8   ences are thereby found to exceed a popular-object threshold.

1   20.   An electromagnetic signal as defined in claim 19 wherein the garbage collector

2 makes the popular-region determination as part of maintaining the remembered sets.

1   21.   An electromagnetic signal as defined in claim 17 wherein the normal-region de-

2 termination's result is negative if the reference satisfies a popular-object-region criterion.

1   22.   An electromagnetic signal as defined in claim 21 wherein the popular-object-

2 region determination's result is negative if the reference is a distinguished, NULL value

3 that indicates that the reference refers to no object.

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1   23.   An electromagnetic signal as defined in claim 22 wherein the popular-object-

2   region criterion is that the reference's value be less than a popular-object-region thresh-

3   old.

1   24.   An electromagnetic signal as defined in claim 23 wherein the NULL value is less

2   than the popular-object-region threshold.

1   25.   A method of employing a computer system as a virtual machine that responds to

2   virtual-machine code, which virtual-machine code defines a mutator that dynamically

3   allocates memory in a heap to data objects and writes in reference fields references to

4   such objects, by causing the computer system to:

5   A)   executing a garbage collector that:

6   i)   treats the heap as divided into regions;

7   ii)   determines whether objects to which memory in the heap has been

8   dynamically allocated satisfy a popular-object criterion;

9   iii)   places into certain, popular-object regions the objects that it

10   thereby determines satisfy such a criterion and excludes from such

11   regions objects that it thereby determines do not satisfy such a cri-

12   terion;

13   iv)   maintains for each of a plurality of the regions other than the popu-

14   lar-object regions a respective remembered set that lists where ref-

15   erences in other regions to that region have been written; and

16   v)   updates the remembered sets in response to reference-written noti-

17   fications from the mutator; and

18   B)   so execute the mutator that, in at least some situations in which the muta-

19   tor writes a reference into a reference field in the heap, the mutator:

20   i)   makes a normal-region determination of whether the reference re-

21   fers to an object that is not located in a popular-object region;

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22   ii)   makes a reference-written notification to the garbage collector if

23   the normal-region determination's result is that the reference refers

24   to an object that is not located in a popular-object region; and

25   iii)   otherwise refrains from making such a notification.

1   26   A method as defined in claim 25 wherein:

2   A)   the garbage collector treats the heap as additionally divided into cards;

3   B)   the mutator maintains at least one remembered-set log; and

4   C)   the reference-written notification includes placing into one such remem-

5   bered-set log an identifier of the card in which the reference's containing

6   object starts.

1   27   A method as defined in claim 25 wherein the garbage collector makes a popular-

2   region determination of whether regions that are not popular-object regions satisfy a

3   popular-region criterion and, when such a region is thereby determined to satisfy the

4   popular-region criterion:

5   A)   counts references to objects in the region with which that remembered set

6   is associated; and

7   B)   places into popular-object regions objects to which the numbers of refer-

8   ences are thereby found to exceed a popular-object threshold.

1   28.   A method as defined in claim 27 wherein the garbage collector makes the popu-

2   lar-region determination as part of maintaining the remembered sets.

1   29.   A method as defined in claim 25 wherein the normal-region determination's result

2   is negative if the reference satisfies a popular-object-region criterion.

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1   30.   A method as defined in claim 29 wherein the popular-object-region determina-

2   tion's result is negative if the reference is a distinguished, NULL value that indicates that

3   the reference refers to no object.

1   31.   A method as defined in claim 30 wherein the popular-object-region criterion is

2   that the reference's value be less than a popular-object-region threshold.

1   32.   A method as defined in claim 31 wherein the NULL value is less than the popu-

2   lar-object-region threshold.

1   33.   A virtual machine that responds to virtual-machine code, which virtual-machine

2   code defines a mutator that dynamically allocates memory in a heap to data objects and

3   writes in reference fields references to such objects, the virtual machine including:

4   A)   a garbage collector that treats the heap as divided into regions and com-

5   prises:

6   i)   means for determining whether objects to which memory in the

7   heap has been dynamically allocated satisfy a popular-object crite-

8   rion;

9   ii)   means for placing into certain, popular-object regions the objects

10   that it thereby determines satisfy such a criterion and excludes

11   from such regions objects that it thereby determines do not satisfy

12   such a criterion;

13   iii) means for maintaining for each of a plurality of the regions other

14   than the popular-object regions a respective remembered set that

15   lists where references in other regions to that region have been

16   written; and

17   iv)   means for updating the remembered sets in response to reference-

18   written notifications from the mutator; and

B) means for so executing the mutator that, in at least some situations in which the mutator writes a reference into a reference field in the heap, the mutator:

      i)   makes a normal-region determination of whether the reference refers to an object that is not located in a popular-object region;

      ii)   makes a reference-written notification to the garbage collector if the normal-region determination's result is that the reference refers to an object that is not located in a popular-object region; and

      iii) otherwise refrains from making such a notification.

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